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SHADZO: A COMPUTER PROGRAM FOR ESTIMATING THE POSITION AND SHAPE OF THE SURFACE SHADOW ZONE IN SONAR OPERATIONS

Bernard de Raigniac, et. al

SACLANT ASW Research Centre
La Spezia, Italy

15 November 1972

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by

BERNARD DE RAIGNIAC and JOHN PADLEY

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NORTH
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VIALE SAN BARTOLOMEO 400
I - 19026 - LA SPEZIA, ITALY

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SHADZO: A COMPUTER PROGRAM FOR ESTIMATING THE POSITION AND SHAPE OF THE SURFACE SHADOW ZONE IN SONAR OPERATIONS

by

Bernard de Raigniac and John Padley

ABSTRACT

SHADZO is a composite program which calculates the position and shape of the first surface shadow zone as a function of the source depth for a given sound speed profile. The program is small enough to be run on a shipboard mini-computer in a few minutes.

INTRODUCTION

It has been found from SACLANTCEN's reverberation studies that information on the position and extent of the surface shadow zone* is needed during at-sea experiments. Thus, a program has been developed which, given the sound speed profile, calculates the pertinent characteristics of the shadow zone and can be run on a shipboard mini-computer in a few minutes. In order to make the maximum possible information available to the scientists aboard ship, the program also includes the estimation of shadow zone shape.

SHADZO (surface SHADow ZOne program) is a composite program which calculates the position and shape of the surface shadow zone, as a function of the source depth, for a given sound speed profile. These characteristics are obtained by direct investigation of the limiting rays, rather than by representation of the sound field by ray-tracing with a high density of rays.

This memorandum describes the theoretical basis for, and the implementation of, the two basic parts of SHAZDO: (1) a part that calculates the distance (i.e., the inner range limit), the extent and the maximum thickness as functions of source depth, and (2) a part that estimates the shape of the shadow zone for selected source depths. A flow chart, a listing, and explanatory diagrams of SHAZDO are given in Appendix A.

---

* The surface shadow zone treated here is the first (i.e., shortest-range shadow zone; the recurring surface shadow zones at longer ranges are not covered.

1. THEORY: POSITION AND SHAPE OF THE SURFACE SHADOW ZONE

1.1 Background

When the sound source is located above the critical depth*, z_{crit}, there is a shadow zone along the surface at certain ranges. This surface shadow zone has been discussed by Mellberg, who calls it "shadow layer", in Ref. 1 . Mellberg provides formulae for the maximum thickness and horizontal extent of the shadow zone, based on a 2-layer, constant gradient model of the medium. The present memorandum provides a further description of the characteristics of the shadow zone, based on a multi-layer, constant-gradient model.

Figures 1 and 2 illustrate the formation of the surface shadow zone in a medium approximated by a two-layer, constant-gradient model. Figure 1a shows the rays which limit the shadow zone, both in range and depth, when the source is between the surface and the minimum-speed-depth, z_m. At the surface, the shadow zone is bounded by rays which have zero grazing angle. The maximum depth, or maximum thickness of the shadow zone, is the depth at which the ray that was horizontal at the source becomes horizontal again. When the source is located between the minimum-speed depth z_m and the critical depth, z_{crit}, as in Fig. 1b, a shadow zone of smaller range extent and smaller maximum thickness will occur.

Figure 2 illustrates the distance, extent and maximum thickness of the shadow zone, again for a 2-layer model. The multi-layer model will be introduced next, and then these three characteristics will be discussed in turn.

---

* The critical depth is the depth at which the sound speed is the same as at the sea surface

In SHADZO, a multi-layer, constant-gradient model of the medium is used. The rays propagate along circle segments in each layer, as illustrated in Fig. 3. The radius of the path in the ith layer is given by:

$$R_i = \frac{k}{g_i} \qquad \text{[Eq. 1]}$$

where

k = Snell's constant of the ray

= $c/\cos\alpha$ (at any depth)

g_i = gradient in the ith layer

$$= \frac{c_i - c_{i-1}}{\Delta z_i} .$$

The horizontal distance travelled by the ray in the ith layer is then:

$$\Delta d_i = R_i(\sin\alpha_{i-1} - \sin\alpha_i)$$

$$= \Delta z_i \frac{\sqrt{k^2 - c_{i-1}^2} - \sqrt{k^2 - c_i^2}}{c_i - c_{i-1}} . \qquad \text{[Eq. 2]}$$

1.2 Distance

The distance to the shadow zone, as illustrated in Fig. 2, is defined as the inner range limit of the shadow zone at the surface. Appendix A of Ref. 2 provides formulae for the distance, for both 2-layer and multi-layer constant-gradient models.

From Eq. 2, we see that the total horizontal distance, d, travelled by a ray in traversing n layers between the source depth and the surface is given by

$$d = \sum_{i=1}^{n} \Delta d_i = \sum_{i=1}^{n} \Delta z_i \frac{\sqrt{k^2 - c_{i-1}^2} - \sqrt{k^2 - c_i^2}}{c_i - c_{i-1}} .$$

To avoid computing errors when $c_i \approx c_{i-1}$, this expression may be transformed into

$$d = \sum_{i=1}^{n} \Delta z_i \frac{c_{i-1} + c_i}{\sqrt{k^2 - c_{i-1}^2} + \sqrt{k^2 - c_i^2}} . \qquad \text{[Eq. 3]}$$

d may be expressed as a function of grazing angle at the surface, γ, by writing $k = c_0/\cos\gamma$. Thus, we see that the distance to the shadow zone, D, is obtained from Eq. 3 simply by setting $\gamma = 0$; then, we have $k = c_0$ and

$$D = \sum_{i=1}^{n} \Delta z_i \frac{c_{i-1} + c_i}{\sqrt{c_0^2 - c_{i-1}^2} + \sqrt{c_0^2 - c_i^2}} . \qquad \text{[Eq. 4]}$$

1.3 Extent

The horizontal extent of the shadow zone at the surface is determined by two rays having zero grazing angle, as illustrated in Fig. 2. It can be seen from Fig. 2 that the horizontal distance travelled by the long-range limiting ray in going between source depth and critical depth is a measure of the extent of the shadow zone. Thus, the extent is given by

$$E = 2 \sum_{i=n+1}^{k} \Delta z_i \frac{c_{i-1} + c_i}{\sqrt{c_0^2 - c_{i-1}^2} + \sqrt{c_0^2 - c_i^2}} \qquad \text{[Eq. 5]}$$

where it is assumed that there are n layers between the source depth and the surface and k layers between the critical depth and the surface.

1.4 Maximum Thickness

As discussed in Ref. 1 and illustrated in Figs. 1 and 2, the maximum depth of the shadow zone is the depth where a ray that was horizontal at the source becomes horizontal again. At this depth, z_t, the sound speed is equal to c_s, the sound speed at source depth.

1.5 Shape

The shape of the shadow zone can be defined as the envelope of the downward-refracted rays, as illustrated by the dashed curves in Fig. 1. This envelope is relatively difficult to calculate exactly, so an estimate of the shape is obtained as follows. First, at closely-spaced depths, we determine the locus of points at which rays vertex (i.e. become horizontal). For the case shown in Fig. 1b, we see that this locus would provide a reasonable estimate of the envelope*. Figure 4 illustrates the case of a limiting ray, such as might be encountered in the presence of a strong negative gradient; in this case, the locus of vertices is not a good estimate. To improve the estimate, at each depth, the intersections of rays vertexing at shallower depths are determined. Finally, at each depth, that point (vertex or intersection) is used which results in the smallest extent of the shadow zone. The estimation of shadow zone shape from these vertices and intersections is illustrated in Fig. 4.

* It would be clearly not provide a reasonable estimate for the case in Fig. 1a; however, this case is not addressed here, as the shape estimation part of SHADZO has been implemented only for cases in which $z_s > z_m$.

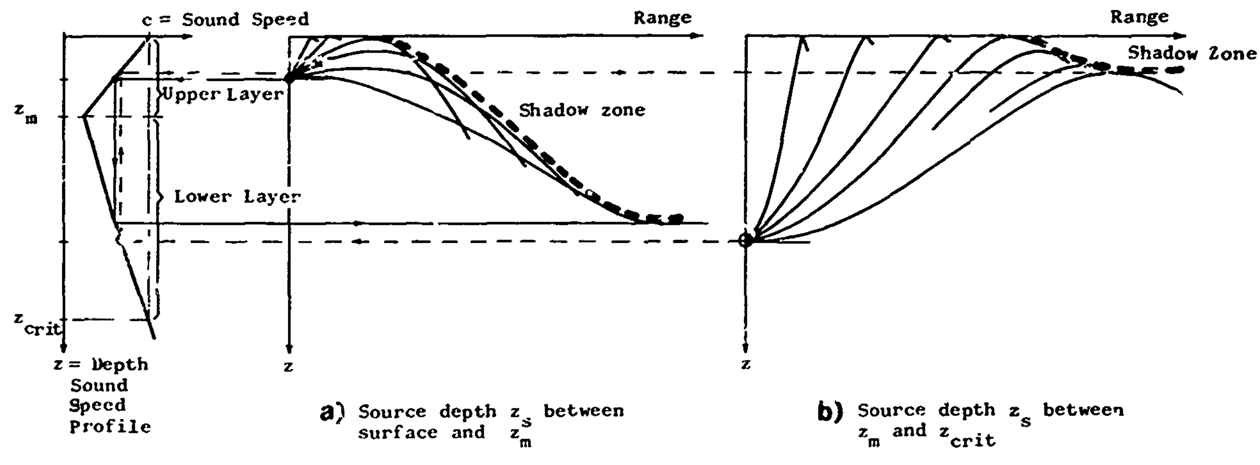


FIG. 1 FORMATION OF THE SHADOW ZONE

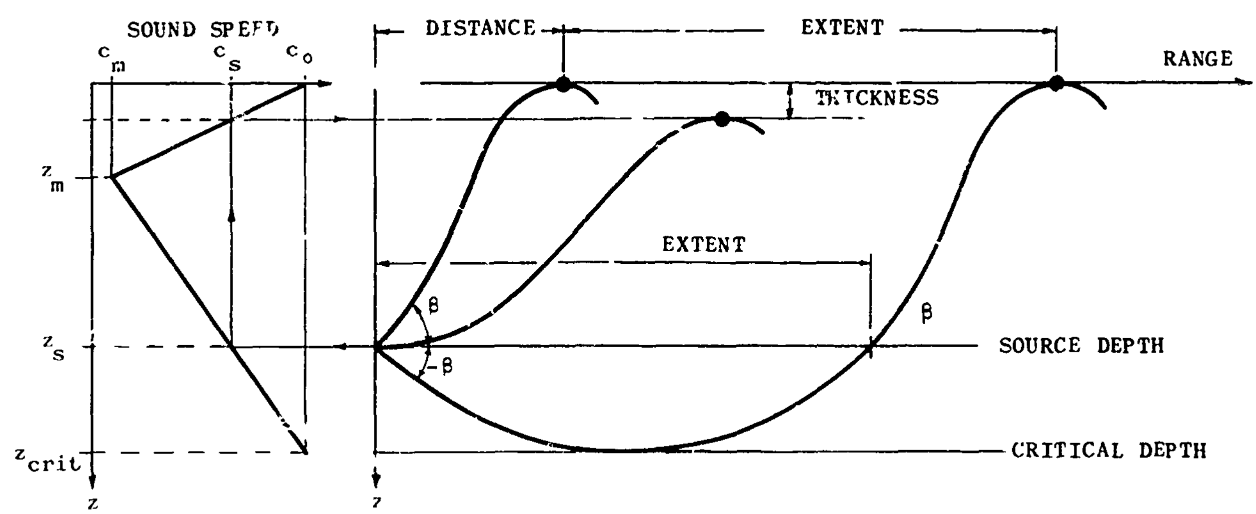


FIG. 2 DISTANCE, EXTENT AND MAXIMUM THICKNESS OF THE SHADOW ZONE

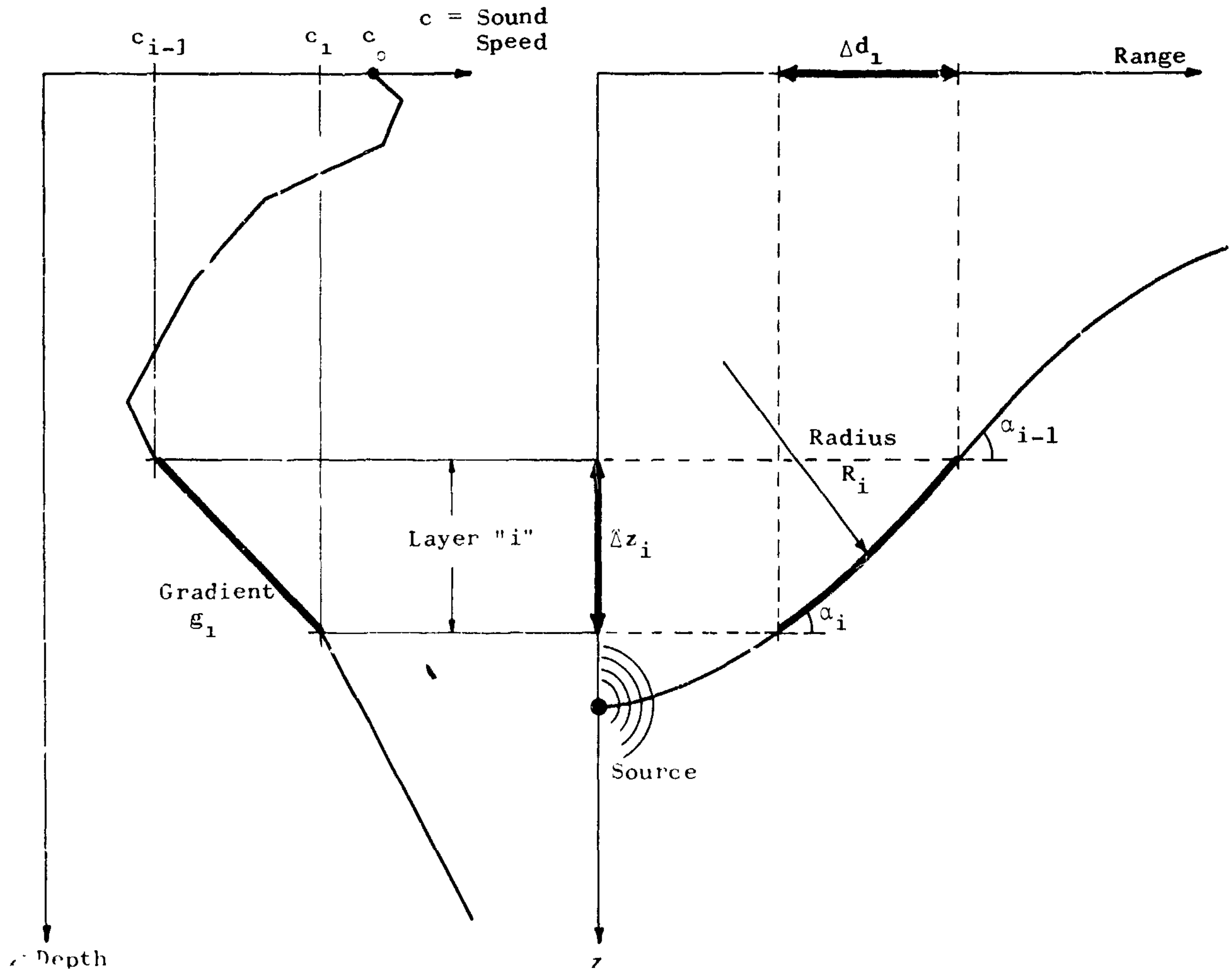


FIG. 3 RAY PATH IN A MULTI-LAYER, CONSTANT-GRADIENT MEDIUM

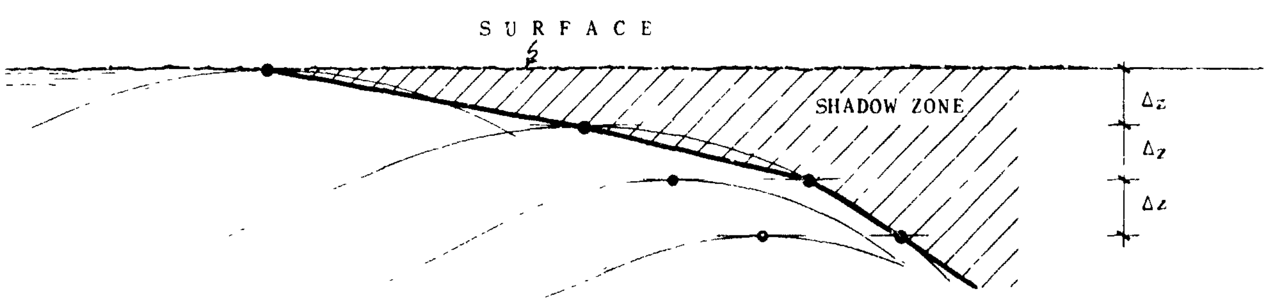


FIG. 4 ESTIMATION OF SHADOW ZONE SHAPE

2. DESCRIPTION OF THE SHADZO PROGRAM

2.1 Hardware Configuration

The program was written to run under the Hewlett-Packard Real-Time System [Ref. 3], and thus requires a minimum hardware configuration of:

H-P 2116B Computer with 16K Memory

H-P 12578A Direct Memory Access

H-P 12579A Extended Arithmetic Unit

H-P 12591A Memory Protect

Fixed Head Disc or Drum Storage Unit

Time Base Generator

Operator Console (ASR-33 or ASR-35 Teleprinter)

In addition, the SHADZO program requires a Tektronix T4002/4802 Graphic Computer Terminal with Tektronix Joystick 015-0175000 and Hard Copy Unit 4601. The Tektronix Terminal can be used in place of the operator console, if an additional paper-tape input device is available. In the absence of a Tektronix Terminal, the program can still produce a printed output on any output writer.

2.2 Software Configuration

The program requires a Real-Time System generated to provide a minimum background disc-resident area of 20K (octal) locations. The Tektronix Terminal should be allocated logical unit number 16 and should be used with the Real-Time teleprinter driver DRV00.

2.3 Program Inputs

The data are input to the program via a punched tape containing the temperature or sound speed profile. Table 1 gives an example of such a profile, as well as the required format.

TABLE 1

TYPICAL DATA TAPE

```
FL 11
29,7,71,1,4Ø
-16
Ø ,24.4
6 ,23.5
8 ,22.8
12,22.2
16,19.5
18,18
2Ø,16.5
24,15.5
28,14.8
4Ø,14.3
64,13.5
18Ø,13.5
25Ø,13.45
4ØØ,13.4
45Ø,13.35
25ØØ,13.35
```

- FL 11 — Profile name — up to 6 alphanumeric characters.
- 29,7,71,1,4Ø — Day, Month, Year, Hour, Minute — 5 integers.
- -16 — No. of points on the profile - integer, negative for temperatures, positive for velocities.
- Ø ,24.4 … 25ØØ,13.35 — Temperature or velocity profile. Pairs of points giving depth in metres and temperature in °C or velocity in m/s .

In the conversion from temperature profile to sound speed profile [according to the Leroy formula (Ref. 4)], the salinity and longitude are considered constants, being pre-set to 38.6 parts/thousand and 40°, respectively. Source depth values are input via the Operator Console.

2.4 Program Details

The SHADZO* program is written in Fortran II, with the exception of the routines for the Tektronix Terminal, which are standard SACLANTCEN library routines written in Assembler Code.

The program consists of four basic sections, as follows:

Section One Reading of the data tape tape, and conversion of temperatures to sound speeds if necessary.

Section Two: Calculation and printing of distance, extent and maximum thickness.

Section Three: Calculation and graphical display of distance, extent and maximum thickness.

Section Four: Calculation and graphical display of shadow zone shape.

The first section is performed once for each set of data; the other sections are performed as many times as required.

Sections two and three can be run with two alternative models of the sound speed profile: (1) a multi-layer, constant-gradient model, using all of the sound speeds calculated from the Leroy formula; and (2) an approximation using two constant-gradient layers.

---

* Because of the restriction in H-P Fortran II which allows only five characters per identifier, the program name actually used is "SHAZO". There are some discrepancies between the terminology used in the text of this memorandum and the terminology used in the program and its outputs shown below. The correspondence is as follows :

Term in Text	Term in Program
Sound speed	Velocity
Maximum thickness	Thickness
Distance	Range
Extent	Extension

A flow chart and listing of the program, together with diagrams indicating the significance of variable names for points on the sound speed profile, are given in the appendix.

2.5 Program Outputs

The outputs from the program are prints and plots, as described below.

2.5.1 Prints

a. Sound speed profile: A sample output is given in Table 2.

TABLE 2

EXAMPLE OF SOUND SPEED PROFILE OUTPUT

SHADOW ZONE PREDICTIONS

XBT FL 11 DATE 29-7-71 TIME 1-4Ø

DEPTHS METRES	VELOCITIES METRES/SEC
.ØØ	1537.3
6.ØØ	1535.2
8.ØØ	1533.5
12.ØØ	1532.1
16.ØØ	1525.Ø
18.ØØ	152Ø.8
2Ø.ØØ	1516.4
24.ØØ	1513.5
28.ØØ	1511.4
4Ø.ØØ	151Ø.Ø
64.ØØ	15Ø7.8
18Ø.ØØ	15Ø9.7
25Ø.ØØ	151Ø.7
4ØØ.ØØ	1513.Ø
45Ø.ØØ	1513.7
25ØØ.ØØ	1548.Ø

b. Distance, extent and maximum thickness: An example is given in Table 3 for the multi-layer model. The output from the two-layer model has a similar format.

TABLE 3

EXAMPLE OF SHADOW ZONE CHARACTERISTICS OUTPUT

MULTILAYER MODEL

SOURCE DEPTH METRES	EXTENSION METRES	RANGE METRES	THICKNESS METRES	S. VELOCITY M/SEC
100.0	35826.4	794.3	57.5	1508.40
200.0	34794.9	1310.0	39.8	1510.00
300.0	33733.8	1840.6	27.8	1511.48
400.0	32640.1	2387.4	24.9	1513.02
500.0	31511.9	2951.6	22.6	1514.52
600.0	30341.5	3536.8	20.3	1516.20
700.0	29122.7	4146.2	19.3	1517.87
800.0	27849.2	4782.9	18.6	1519.55
900.0	26513.1	5451.0	17.8	1521.22
1000.0	25104.4	6155.3	17.0	1522.90
1100.0	23610.1	6902.5	16.2	1524.57
1200.0	22012.7	7701.2	15.3	1526.25
1300.0	20288.1	8563.5	14.4	1527.92
1400.0	18400.3	9507.4	13.4	1529.59
1500.0	16292.9	10561.1	12.5	1531.27
1600.0	13865.9	11774.6	9.6	1532.94
1700.0	10908.2	13253.4	6.7	1534.62
1800.0	6755.3	15329.9	3.0	1536.29

2.5.2 Plots

All graphical outputs are plotted on the Tektronix Terminal and have a similar format. The results are plotted on a 5 x 5 grid and a scale factor for each parameter is printed on the display; this scale factor is the number of metres equivalent to one division of the display (i.e., full scale is five times the scale factor). At the end of each display, a copy is produced on the Hard Copy Unit. The origin of the plot is the upper left hand corner; the vertical

parameter is depth and the other relevant parameter is plotted horizontally.

a. Distance, extent and maximum thickness: one plot is produced for each parameter. Examples are given in Fig. 5.

b. Shape: One plot is produced. If more than one source depth is requested, all outputs are plotted on the same graph to the same scale. An example is given in Fig. 6.

2.6 Operation

To run the program, load the data tape in the tape reader and enter the program (under the Real-Time System, this is effected by typing "ON, SHADZO" on the Operator Console). If the last point on the temperature or sound speed profile is not deep enough to allow the critical depth to be calculated, the computer prints:

THE LAST POINT OF THE B.T. IS ABOVE THE CRITICAL DEPTH

and the program ends. In this case, the data tape must be retyped. Once a correct data tape has been read and the sound speed profile has been calculated and listed as shown in Table 2, the computer will print:

FOR SHADOW ZONE SHAPE TYPE 1 OTHERWISE TYPE -1 *

2.6.1 Distance, Extent and Maximum Thickness:

If -1 is replied to the question about shadow zone shape, the computer outputs:

FOR GRAPHIC OUTPUT TYPE 1 OTHERWISE TYPE -1

* All questions of this type should be answered by either -1 or 1, followed by carriage return, line feed.

and after the response to this request, the computer outputs:

FOR MULTILAYER TYPE 1, FOR 2 LAYER TYPE -1

When the type of model has been selected, if no graphic output was requested, then the computer prints:

TYPE IN S.DEPTH: START, STEP, END

The source depths for which output is required should then be typed in, giving the minimum depth first, and with values separated with commas. No output is produced for source depths greater than the critical depth. When the source depth has been input, the results are calculated and printed.

If graphic output is selected, then the three graphs are displayed and after the last output, the joystick is enabled and the computer prints:

TO EXPAND PLOT POSITION CURSOR AT MAXIMUM SOURCE DEPTH REQUIRED AND TYPE 1 OTHERWISE TYPE Ø

If an expansion is required, then the horizontal line of the cursor should be placed at the maximum source depth for the new plots and 1 should be typed. A new set of displays is then produced, and the expansion option is repeated. (It is not possible at this stage to increase the maximum source depth of the display. If this is required, the program must be continued and reprocessing of the same data requested. See below). If expansion of the plots is not required, type 0.

2.6.2 Shadow Zone Shape

If the shape is requested, then the source depths are requested as for the printer output above. The source depths must be below the depth of minimum sound speed; if the starting depth is less than this value, then it is automatically adjusted to this value.

If the source depth exceeds the critical depth, the calculation stops. If only one source depth is required, the second and third parameters should be zero. The computer then calculates and displays the shape.

2.6.3 Termination

After the relevant output has finished, the computer prints:

TYPE Ø TO REPROCESS, 1 TO PROCESS NEW DATA OR 2 TO STOP

If the response is 0, the program returns to the point at which it asks if the shadow zone shape is required. If the response is 1, a new data tape is read and processing restarts. If the response is 2, the program ends.

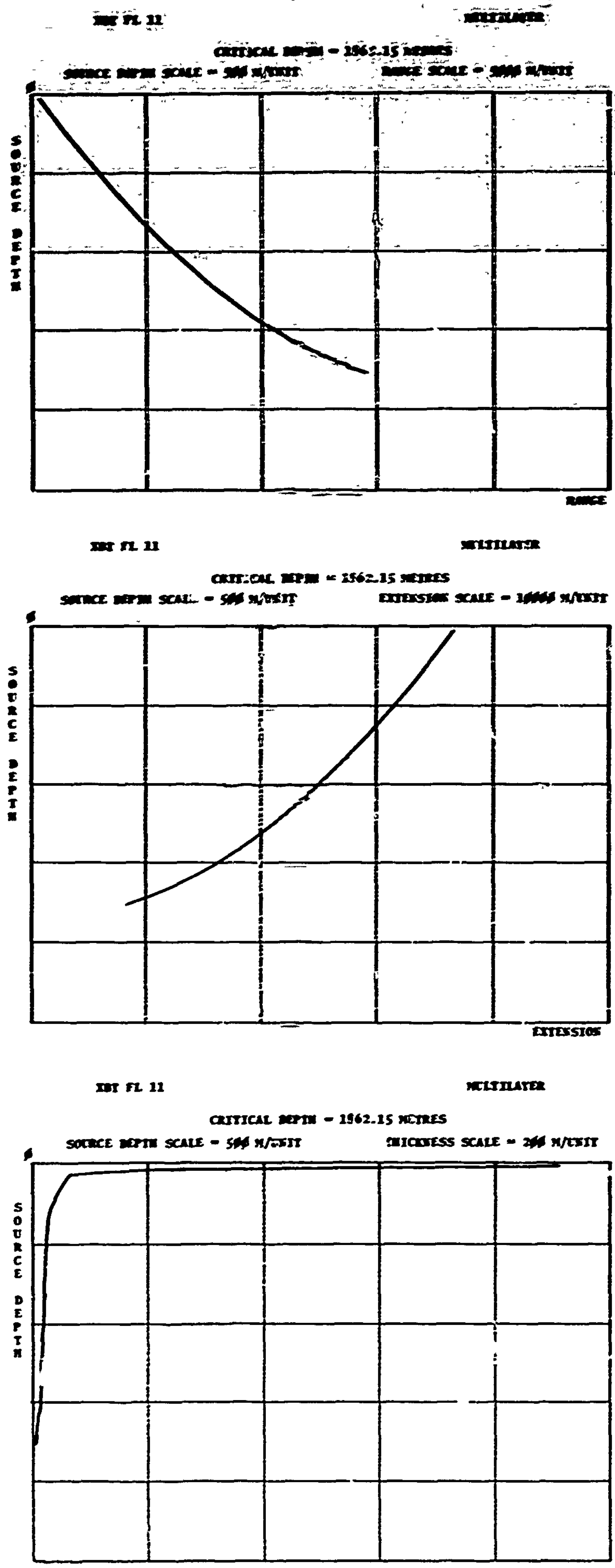


FIG. 5 EXAMPLES OF DISTANCE (RANGE), EXTENT (EXTENSION) AND MAXIMUM THICKNESS PLOTS

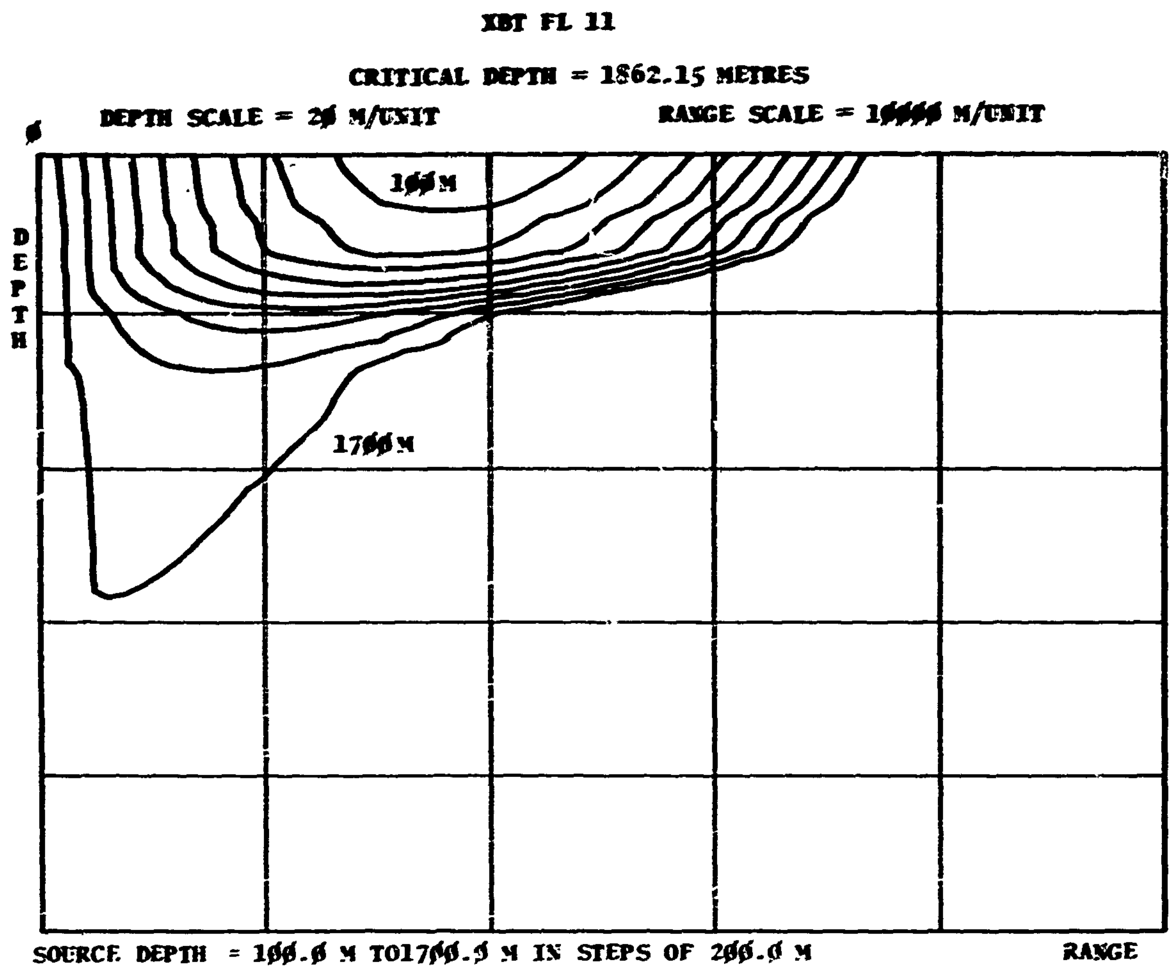


FIG. 6 EXAMPLE OF SHADOW ZONE SHAPE PLOT

REFERENCES

1. Mellberg, L.E., "Optimum Sonar Transducer Depths for Decreasing the Effects of Surface Reverberation (NU)", SACLANTCEN Technical Report No. 167, April 1970, NATO CONFIDENTIAL. [AD No. 510 235]

2. Bachmann, W. and de Raigniac, B., "The Calculation of the Surface Backscattering Coefficient of Underwater Sound from Measured Data", SACLANTCEN Technical Memorandum No. 174, November 1971, NATO UNCLASSIFIED. [AD No. 735 995]

3. "Real Time Software, A Reference Text for Programmers", Hewlett-Packard Co. Document No. HP 02005-90002, October 1971.

4. Leroy, C.C., "Development of Simple Equations for Accurate and More Realistic Calculation of the Speed of Sound in Sea Water", SACLANTCEN Technical Report No. 128, November 1968, NATO UNCLASSIFIED. [AD No. 845 866]

APPENDIX A

DETAILED PROGRAM INFORMATION

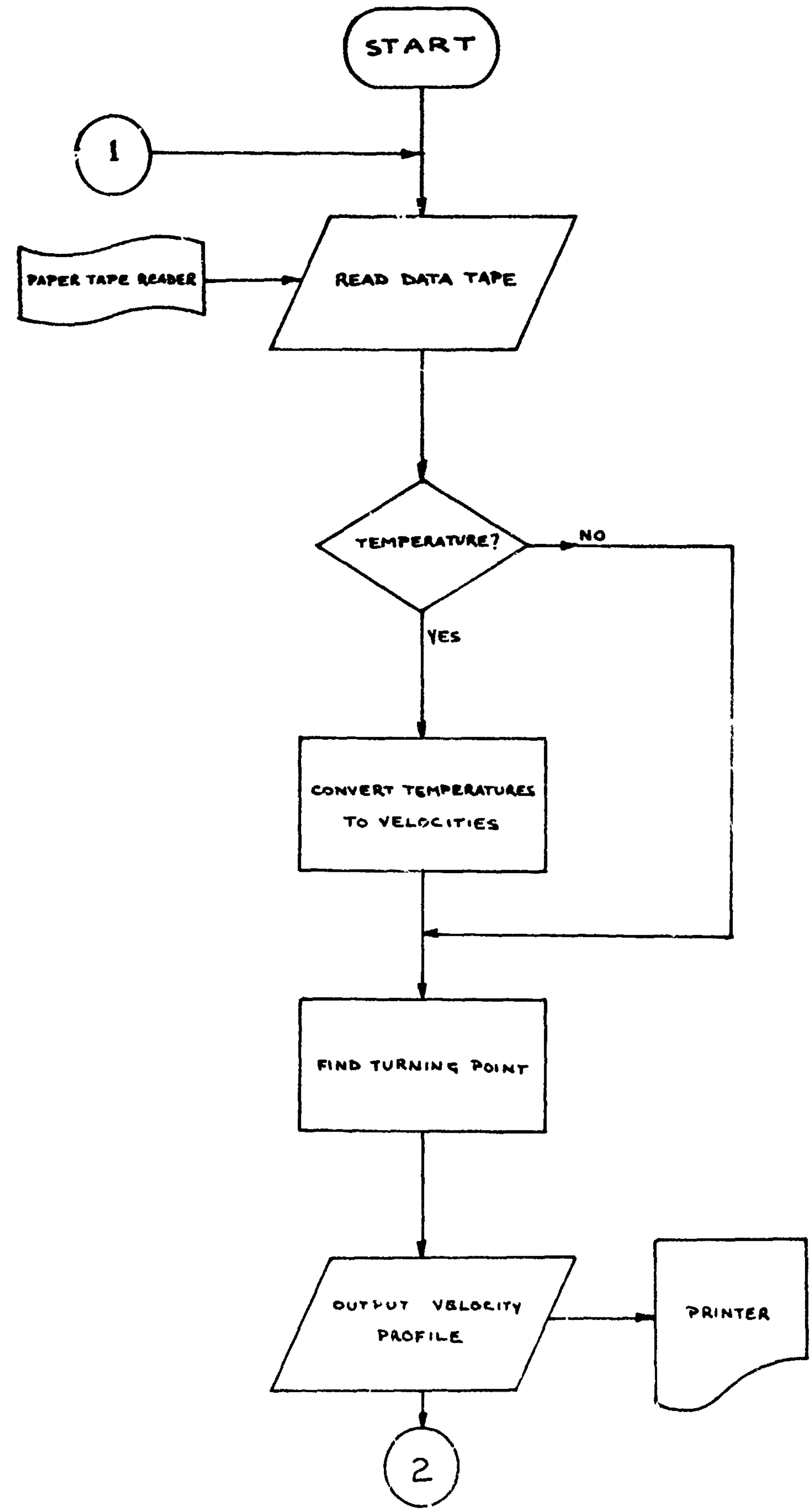
A.1 Flow Chart

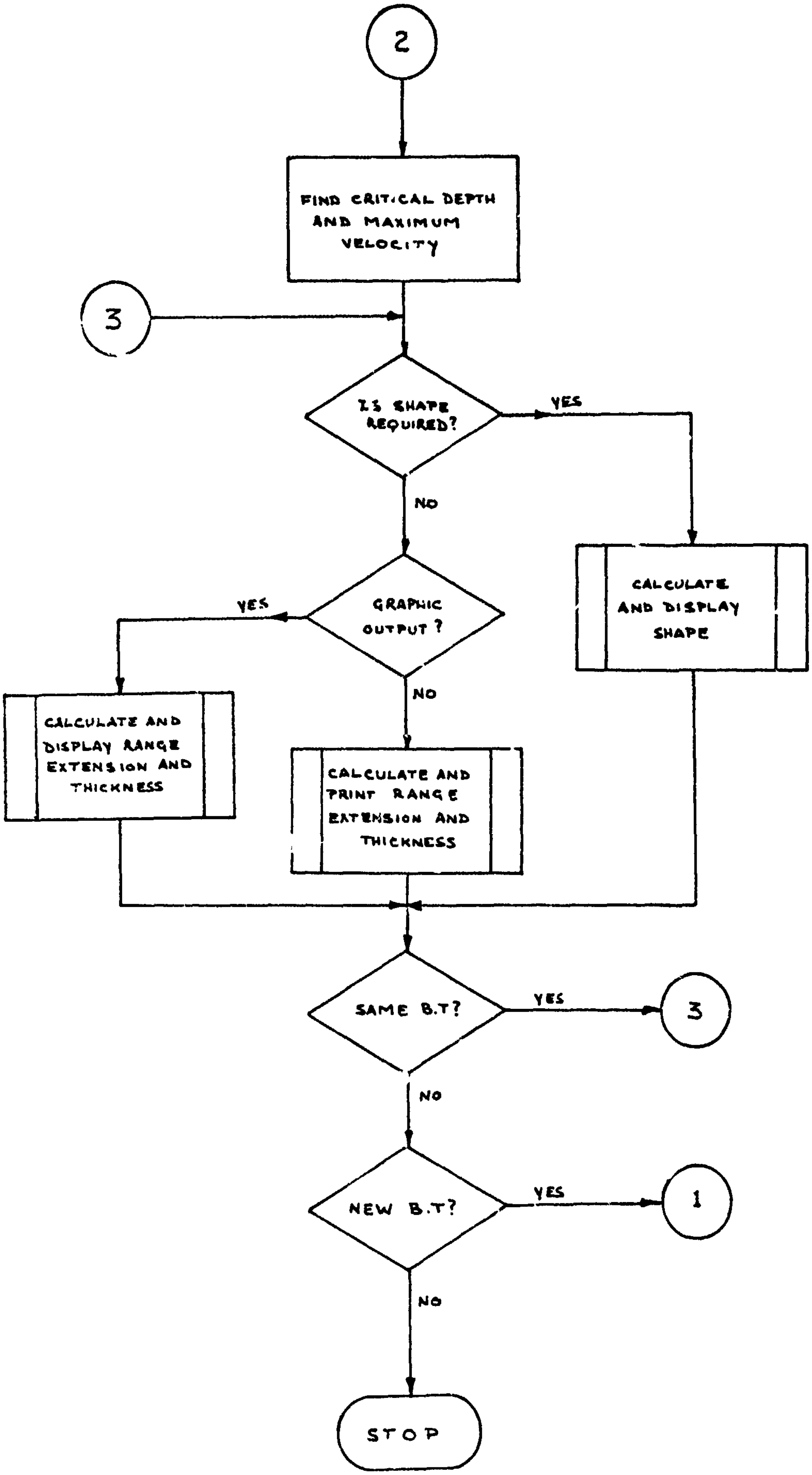
A.2 Explanatory Diagrams and Program Listing

Note: The word "velocity" used in this Appendix corresponds to the words "sound speed" used in the Main Text.

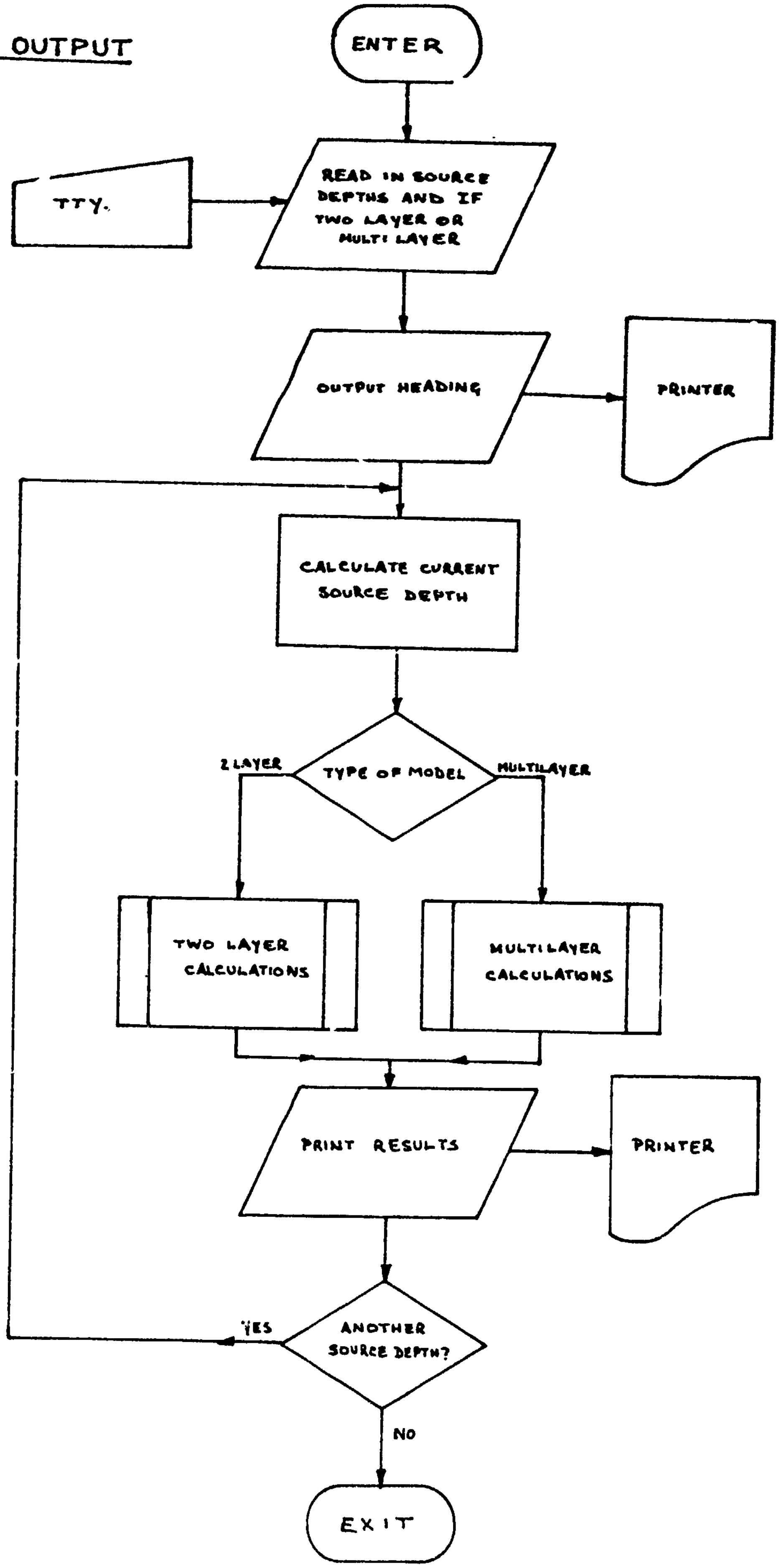
A.1 Flow Chart

SHADZO FLOW CHART

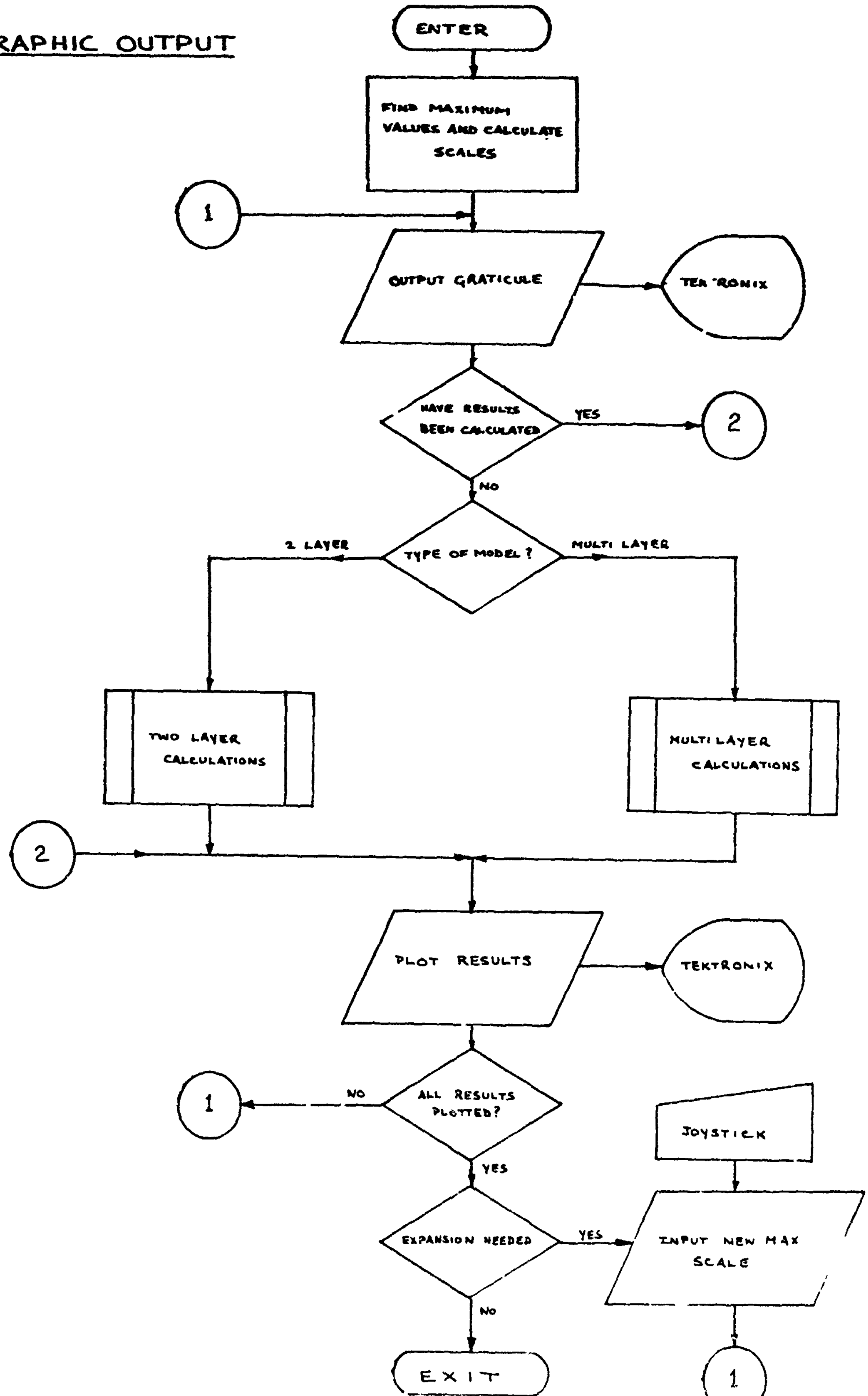



2
FIND CRITICAL DEPTH AND MAXIMUM VELOCITY
3
IS SHAPE REQUIRED?
YES
NO
CALCULATE AND DISPLAY SHAPE
GRAPHIC OUTPUT ?
YES
NO
CALCULATE AND DISPLAY RANGE EXTENSION AND THICKNESS
CALCULATE AND PRINT RANGE EXTENSION AND THICKNESS
SAME B.T?
YES
3
NO
NEW B.T?
YES
1
NO
STOP

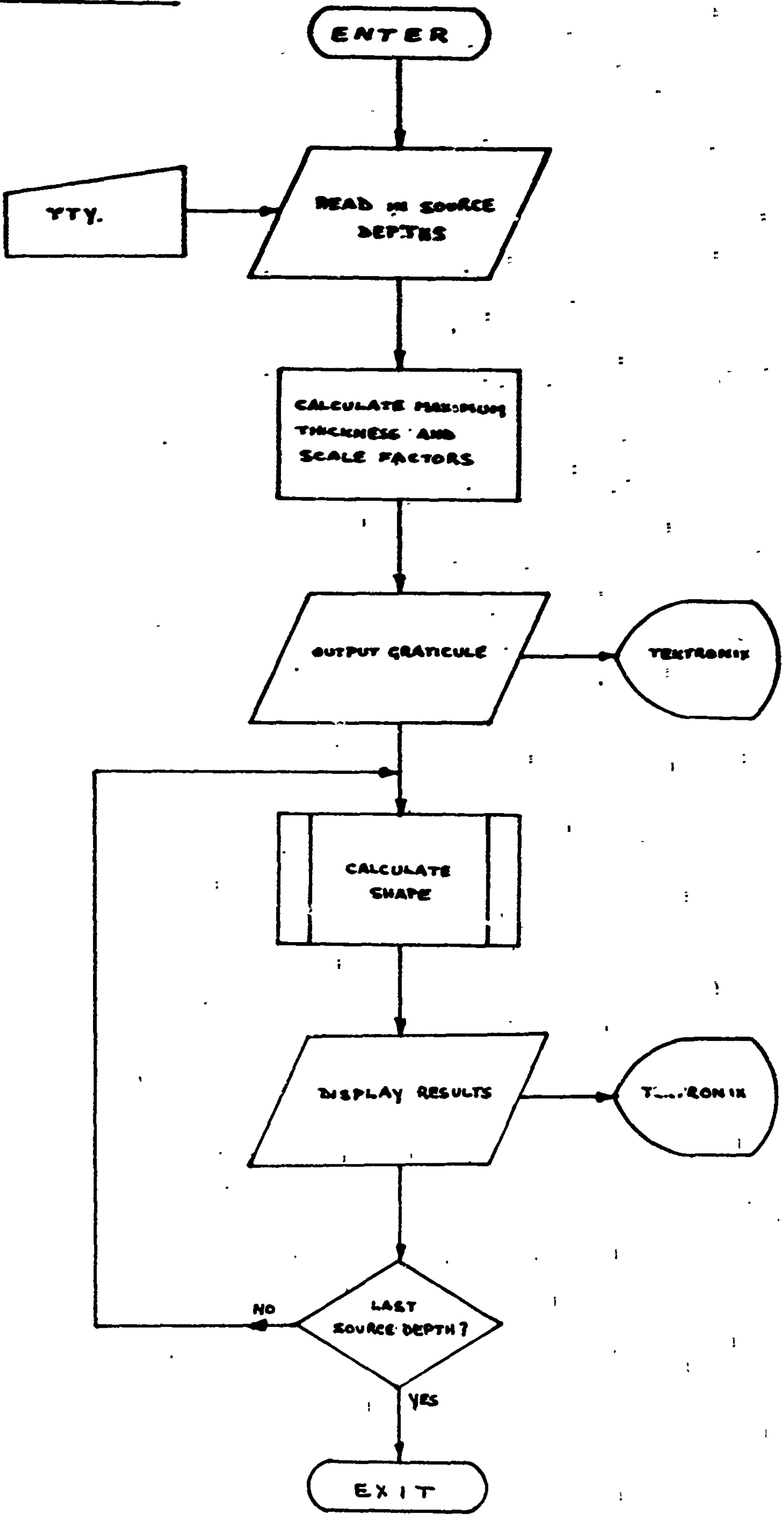
PRINTER OUTPUT



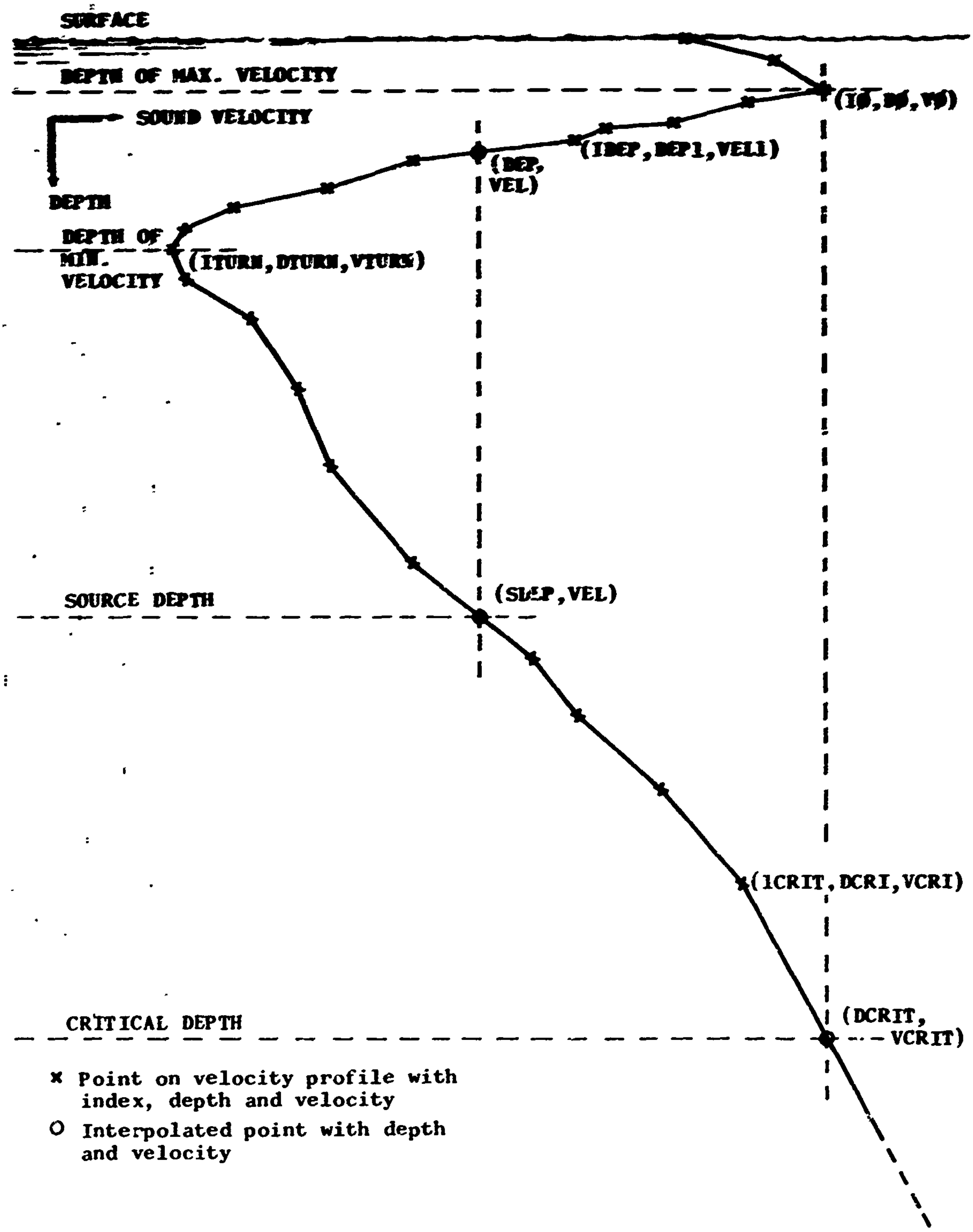
GRAPHIC OUTPUT



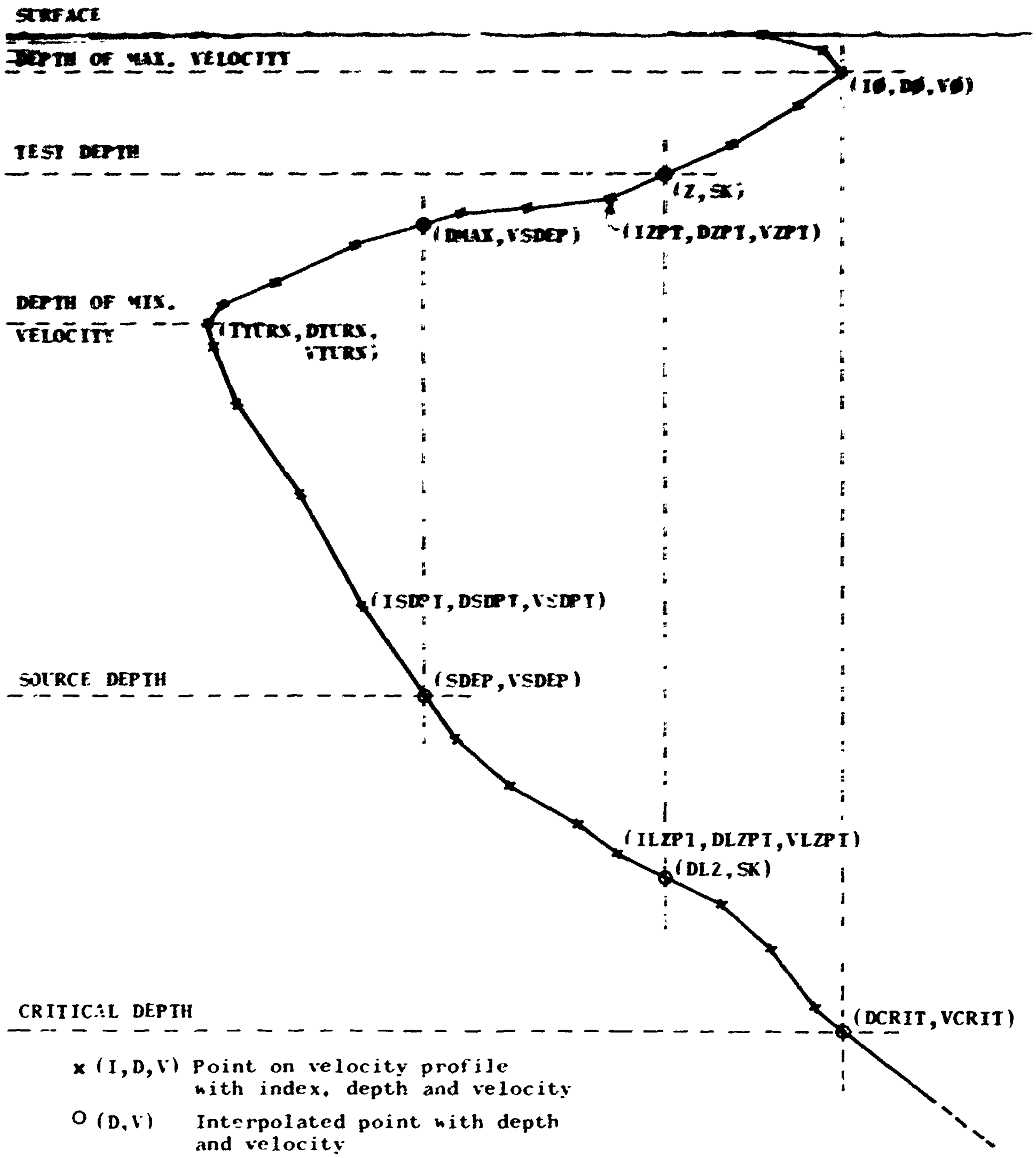
SHAPE OUTPUT



A.2 Explanatory Diagrams and Program Listing



PARAMETERS USED IN CALCULATION OF RANGE, EXTENSION AND THICKNESS



PARAMETERS USED IN CALCULATION OF SHAPE

```
FTN,L
C
C          THIS PROGRAM WAS DEVELOPED AT -
C
C                        SACLANT ASW RESEARCH CENTRE
C                        VIALE SAN BARTOLOMEO 400
C                        19026, LA SPEZIA
C                        ITALY.
C
      PROGRAM SHAZO(3,70)
C
C          J.P. 27-10-71
C
      DIMENSION D(40),V(40),C(40),IASCI(10),INAME(6)
      DIMENSION RA(100),EX(100)
C
C          THIS PROGRAM PREDICTS THE RANGE AND EXTENSION
C     OF THE SHADOW ZONE FOR VARIOUS SOURCE DEPTHS.
C
C          READ DATA TAPE AND CONVERT TEMPERATURES TO
C     VELOCITIES IF NECESSARY.
C
      PHI=42.
      SAL=38.6
   10 DO 20 I=1,6
   20 INAME(I)=20040B
      READ(5,30)(INAME(I),I=1,6)
   30 FORMAT(6A1)
      READ(5,*)IDAY,MONTH,IYEAR,IHOUR,MINUT
      READ(5,*)MODE
      N=IABS(MODE)
      DO 35 I=1,N
   35 READ(5,*)D(I),V(I)
      IF(MODE)40,50
   40 CALL BTRAN(V,D,N,SAL,PHI)
   50 CALL FINTP(V,N,ITURN)
      DTURN=D(ITURN)
      VTURN=V(ITURN)
C
C          OUTPUT HEADING AND VELOCITY PROFILE
C
      CALL EXEC(3,1100B,-1)
      WRITE(6,60)(INAME(I),I=1,6),IDAY,MONTH,IYEAR,IHOUR,MINUT
   60 FORMAT(24X,"SHADOW ZONE PREDICTIONS",//,7X,"XBT ",6A1,
     1     12X,"DATE",I3,2("-",I2),12X,"TIME",I3,"-",I2,//,
     2     5X,"DEPTHS",10X,"VELOCITIES"/5X,"METRES",10X,
     3     "METRES/SEC",/)
      WRITE(6,70)(D(I),V(I),I=1,N)
   70 FORMAT(X,F10.2,F17.1)
C
C          FIND CRITICAL DEPTH ETC.
C
      IF(V(N)-V0)80,100
   80 WRITE(1,90)
   90 FORMAT("THE LAST POINT OF THE B.T. IS ABOVE THE ",
     1     "CRITICAL DEPTH")
```

```
      STOP
  100 VZ=V(1)
      DZ=0.
      IZ=1
      DO 120 I=2,ITURN
      IF(VZ-V(I))110,120
  110 VZ=V(I)
      DZ=D(I)
      IZ=I
  120 CONTINUE
      CALL FINAL(V,D,VZ,DCRIT,ICRIT,N,ITURN)
      VCRIT=VZ
      WRITE(6,130)DCRIT
  130 FORMAT(/,12X,"CRITICAL DEPTH  =",F8.2," METRES"/)
C
C          REQUEST TYPE OF CALCULATION AND OUTPUT
C
  140 WRITE(1,145)
  145 FORMAT("FOR SHADOW ZONE SHAPE TYPE 1 OTHERWISE TYPE -1 <")
      READ(1,*)ISHAP
      IF(ISHAP)150,720
  150 WRITE(1,155)
  155  FORMAT("FOR GRAPHIC OUTPUT TYPE 1 OTHERWISE TYPE -1 <")
      READ(1,*)IGRAP
      WRITE (1,160)
  160 FORMAT("FOR MULTILAYER TYPE 1, FOR 2 LAYER TYPE -1 <")
      READ(1,*)LAYER
      IF(IGRAP)170,350
C
C ************************************************************
C
C          PRINTER OUTPUT
C
  170 WRITE(1,180)
  180 FORMAT("TYPE IN S.DEPTH: START,STEP,END")
      READ(1,*)SD1,SD2,SD3
C
C          OUTPUT HEADING ETC.
C
      CALL EXEC(3,1106B,-1)
      IF(LAYER)190,210
  190 WRITE(6,200)
  200 FORMAT(20X,"TWO LAYER MODEL"/)
      GO TO 230
  210 WRITE(6,220)
  220 FORMAT(20X,"MULTILAYER MODEL"/)
  230 WRITE(6,240)
  240 FORMAT(" SOURCE DEPTH"4X"EXTENSION"7X"RANGE"6X"THICKNESS"
     1     5X,"S. VELOCITY"/,4X,"METRES",8X,"METRES",9X,"METRES",
     2     6X,"METRES",10X,"M/SEC")
C
C          CALCULATE SOURCE DEPTH ETC.
C
      NX=(SD3-SD1)/SD2+1.
      DO 340 I=1,NX
      SDEP=SD1+FLOAT(I-1)*SD2
```

```
      IF(D0-SDEP)250,340
  250 IF(SDEP-DCRIT)260,340
  260 IF(SDEP-DTURN)270,280
  270 CALL FIVAL(D,V,SDEP,VEL,IDEP,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I9,N,ITURN)
      GO TO 290
  280 CALL FIVAL(D,V,SDEP,VEL,IDEP,N,ITURN)
      CALL FIVAL(V,D,VEL,DEP,I9,I0,ITURN)
      CALL FIVAL(D,V,DEP,VEL,I7,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I8,I7,ITURN)
  290 IF(LAYER)300,310
C
C          TWO LAYER MODEL
C
  300 CALL TWO(V0,VCRIT,DCRIT,SDEP,D0,DTURN,VTURN,RANGE,EXT,THICK)
      GO TO 320
C
C          MULTILAYER MODEL
C
  310 CALL MULTI(V0,VEL,VCRIT,DCRIT,SDEP,ICRIT,IDEP,V,D,RANGE,EXT)
      THICK=DEP
C
C          PRINT RESULTS
C
  320 WRITE(6,330)SDEP,EXT,RANGE,THICK,VEL
  330 FORMAT(F10.1,3F14.1,F15.2)
  340 CONTINUE
      GO TO 150
C
C *******************************************************************
C
C          GRAPHIC OUTPUT
C
  350 SDMAX=DCRIT*0.95
      SDMIN=(SDMAX-D0)/100.+D0
C
C          FIND MAXIMUM VALUES
C
  360 IF(LAYER)370,380
  370 CALL TWO(V0,VCRIT,DCRIT,SDMAX,D0,DTURN,VTURN,RAMAX,EX,TH)
      CALL TWO(V0,VCRIT,DCRIT,SDMIN,D0,DTURN,VTURN,RA,EXMAX,THMAX)
      GO TO 420
  380 IF(SDMAX-DTURN)390,400
  390 CALL FIVAL(D,V,SDMAX,VEL,IDEP,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I9,N,ITURN)
      GO TO 410
  400 CALL FIVAL(D,V,SDMAX,VEL,IDEP,N,ITURN)
      CALL FIVAL(V,D,VEL,DEP,I9,I0,ITURN)
      CALL FIVAL(D,V,DEP,VEL,I7,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I8,I7,ITURN)
  410 CALL MULTI(V0,VEL,VCRIT,DCRIT,SDMAX,ICRIT,IDEP,
     1     V,D,RAMAX,EX)
      CALL FIVAL(D,V,SDMIN,VEL,IDEP,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I9,N,ITURN)
      CALL MULTI(V0,VEL,VCRIT,DCRIT,SDMIN,ICRIT,IDEP,
     1     V,D,RA,EXMAX)
```

```
      THMAX=DEP
C
C          CALCULATE SCALE FACTORS
C
  420 ISCSD=ISCAL(SDMAX)
      ISCTH=ISCAL(THMAX)
      ISCRA=ISCAL(RAMAX)
      ISCEX=ISCAL(EXMAX)
      DO 560 J=1,3
C
C          OUTPUT GRATICULE
C
      CALL GRAT(INAME,ISCSD,DCRIT,LAYER,ISHAP)
      CALL DARK(620,644)
      CALL ALPHA
      IF(J-2)430,460,490
  430 WRITE(16,440)ISCTH
  440 FORMAT("THICKNESS SCALE =",I5," M/UNIT")
      CALL DARK(912,15)
      CALL ALPHA
      WRITE(16,450)
  450 FORMAT("THICKNESS←")
      GO TO 520
  460 WRITE(16,470)ISCRA
  470 FORMAT("RANGE SCALE =",I5,"M/UNIT")
      CALL DARK(912,15)
      CALL ALPHA
      WRITE(16,480)
  480 FORMAT("RANGE←")
      GO TO 520
  490 WRITE(16,500)ISCEX
  500 FORMAT("EXTENSION SCALE =",I5," M/UNIT")
      CALL DARK(912,15)
      CALL ALPHA
      WRITE(16,510)
  510 FORMAT("EXTENSION←")
  520 STEP=(SDMAX-D0)/100.
C
C          OUTPUT RESULTS
C
      DO 550 I=1,100
      SDEP=D0+FLOAT(I)*STEP
      IF(J-2)525,530
  525 IF(LAYER)530,540
  530 CALL TWO(V0,VCRIT,DCRIT,SDEP,D0,DTURN,VTURN,
     1      RA(I),EX(I),TH)
      GO TO 580
  540 IF(SDEP-DTURN)550,560
  550 CALL FIVAL(D,V,SDEP,VEL,IDEP,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I9,N,ITURN)
      GO TO 570
  560 CALL FIVAL(D,V,SDEP,VEL,IDEP,N,ITURN)
      CALL FIVAL(V,D,VEL,DEP,I9,I0,ITURN)
      CALL FIVAL(D,V,DEP,VEL,I7,ITURN,1)
      CALL FIVAL(V,D,VEL,DEP,I8,I7,ITURN)
  570 CALL MULTI(V0,VEL,VCRIT,DCRIT,SDEP,ICRIT,IDEP,V,D,
```

```
    1     RA(I),EX(I))
          TM=DEP
C
C             CALCULATE CO-ORDINATES FOR DISPLAY
C
  580 IF(J-2)590,600,610
  590 IX=(TM/FLOAT(ISCTM))*200.+23.
      GO TO 620
  600 IX=(RA(I)/FLOAT(ISCRA))*200.+23.
      GO TO 620
  610 IX=(EX(I)/FLOAT(ISCEX))*200.+23.
  620 IY=531.-(SDEP/FLOAT(ISCSD))*120.
      IF(I-2)630,640
  630 CALL DARK(IX,IY)
      GO TO 650
  640 CALL BRIGHT(IX,IY)
  650 CONTINUE
      CALL HARDC
  660 CONTINUE
      CALL DARK(30,331)
      CALL ALPHA
C
C             REQUEST IF EXPANSION IS REQUIRED
C
      WRITE(15,670)
  670 FORMAT("TO EXPAND PLOT POSITION CURSOR AT MAXIMUM SOURCE ",
     1       "DEPTH REQUIRED AND TYPE 1",/,30X,"OTHERWISE TYPE 0")
      CALL CURSI(ICHAR,IX,IY)                                    C
      IF(ICHAR-49)710,680
C
C             CALCULATE NEW MAXIMUM SOURCE DEPTH
C
  680 SDMAX=(631.-FLOAT(IY))/120.*FLOAT(ISCSD)
      IF(SDMAX-DCRIT*0.95)700,690
  690 SDMAX=DCRIT*0.95
  700 GO TO 360
  710 CALL ERASE
      CALL HOME
      GO TO 1500
C
C ****************************************************************
C
C             CALCULATION AND DISPLAY OF SHADOW ZONE SHAPE
C
  720 WRITE(1,180)
      READ(1,*)SD1,SD2,SD3
      IF(SD1-DTURN-1.)730,740
  730 SD1=DTURN+1.
  740 IF(SD2)750,750,760
  750 NX=1
      GO TO 785
  760 IF(SD3-SD1)770,770,780
  770 NX=1
      GO TO 785
  780 NX=(SD3-SD1)/SD2+1.
C
```

```
C          FIND MAXIMUM VALUES
C
  785 SDEP=SD1
      CALL FIVAL(D,V,SDEP,VSDEP,ISDPT,N,ITURN)
      CALL FIVAL(V,D,VSDEP,DMAX,I,I0,ITURN)
      CALL FIVAL(D,V,DMAX,V1,I1,ITURN,1)
      CALL FIVAL(V,D,V1,DMAX,I,I1,ITURN)
      DO 790 I=2,N
  790 C(I)=(D(I)-D(I-1))*(V(I)+V(I-1))
      Z=(DMAX-D0)/100.
      CALL DSTPS(Z+D0,SDEP,VSDEP,ISDPT,DMAX,I0,ITURN,N,
     1    C,D,V,DIST1,DIST2,RAD)
C
C          CALCULATE SCALE FACTORS
C
      ISCTM=ISCAL(DMAX)
      ISCRA=ISCAL(DIST2)
C
C          OUTPUT GRATICULE
C
      CALL GRAT(NAME,ISCTM,DCRIT,LAYER,ISHAP)
      CALL DARK(600,544)
      CALL ALPHA
      WRITE(16,470)ISCRA
      CALL DARK(0,0)
      CALL ALPHA
      IF(NX-2)890,910
  890 WRITE(16,900)SD1
  900 FORMAT("SOURCE DEPTH =",F6.1," METERS +")
      GO TO 930
  910 WRITE(16,920)SD1,SD3,SD2
  920 FORMAT("SOURCE DEPTH =",F6.1," M TO",F6.1,
     1    " M IN STEPS OF",F6.1," M+")
  930 CALL DARK(912,15)
      CALL ALPHA
      WRITE(16,480)
      DO 1100 J=1,NX
C
C          CALCULATE RESULTS
C
      SDEP=SD1+FLOAT(J-1)*SD2
      CALL FIVAL(D,V,SDEP,VSDEP,ISDPT,N,ITURN)
      CALL FIVAL(V,D,VSDEP,DMAX,I1,I0,ITURN)
      CALL FIVAL(D,V,DMAX,V1,I1,ITURN,1)
      CALL FIVAL (V,D,V1,DMAX,I2,I1,ITURN)
      STEP=(DMAX-D0)/100.
      ZOLD1=0.
      ZOLD2=0.
      RNEW1=0.
      RNEW2=1.E10
      RAD1=0.
      RAD2=0.
      DO 1050 I=1,100
      Z=FLOAT(I)*STEP
      CALL DSTPS(Z+D0,SDEP,VSDEP,ISDPT,DMAX,I0,ITURN,N,
     1    C,D,V,DIST1,DIST2,RAD)
```

```
C
C          FIND WHICH POINTS TO RETAIN
C
      IF(RAD1)940,940,950
  940 RANGE=RNEW1
      GO TO 960
  950 E=(Z-ZOLD1)/RAD1
      RANGE=RNEW1+RAD1*SQRT(E*(2.-E))
  960 IF(DIST1-RANGE)970,980
  970 RA(I)=RANGE
      GO TO 990
  980 RNEW1=DIST1
      RA(I)=DIST1
      ZOLD1=Z
      RAD1=RAD
  990 IF(RAD2)1000,1000,1010
 1000 RANGE=RNEW2
      GO TO 1020
 1010 E=(Z-ZOLD2)/RAD2
      RANGE=RNEW2-RAD2*SQRT(E*(2.-E))
 1020 IF(RANGE-DIST2)1030,1040
 1030 EX(I)=RANGE
      GO TO 1050
 1040 RNEW2=DIST2
      EX(I)=DIST2
      ZOLD2=Z
      RAD2=RAD
 1050 CONTINUE
C
C          DISPLAY RESULTS
C
      DO 1080 I=1,100
      Z=FLOAT(I)*STEP
      IX=(RA(I)/FLOAT(ISCRA))*200.+23.
      IY=531.-(Z/FLOAT(ISCTH))*120.
      IF(I-2)1060,1070
 1060 CALL DARK(IX,IY)
      GO TO 1080
 1070 CALL BRIGH(IX,IY)
 1080 CONTINUE
      DO 1090 II=1,100
      I=101-II
      Z=FLOAT(I)*STEP
      IX=(EX(I)/FLOAT(ISCRA))*200.+23.
      IY=531.-(Z/FLOAT(ISCTH))*120.
 1090 CALL BRIGH(IX,IY)
 1100 CONTINUE
      CALL HARDC
      CALL ERASE
      CALL ALPHA
      CALL HOME
      GO TO 1500
C
C ********************************************************************
C
C          REQUEST NEXT OPERATION
```

```
C
 1500 WRITE(1,1510)
 1510 FORMAT("TYPE 0 TO REPROCESS, 1 TO PROCESS NEW DATA ",
     1     "OR 2 TO STOP")
      READ(1,*)I
      IF(I-1)140,10,1520
 1520 STOP
      END
```

```
FTN,L
C
C          J.P. 22-10-71
C
C          THIS IS THE FIRST SET OF SUBROUTINES FOR THE
C       PROGRAM SHAZO
C
      SUBROUTINE MULTI(V0,VEL,VCRIT,DCRIT,SDEP,ICRIT,IDEP,
     1   V,D,RANGE,EXT)
      DIMENSION V(1),D(1),T(40)
C
C          THIS SUBROUTINE CALCULATES THE RANGE AND EXTENSION OF
C       THE SHADOW ZONE FOR THE MULTILAYER MODEL.
C
      DCRI=D(ICRIT)
      VCRI=V(ICRIT)
      DO 10 I=2,ICRIT
   10 T(I)=SQRT((V0+V(I-1))*(V0-V(I-1)))+SQRT((V0+V(I))*(V0-V(I)))
      DEP1=D(IDEP)
      VEL1=V(IDEP)
C
C          CALCULATE EXTENSION
C
      IF(DEP1-DCRI)20,30
   20 I=IDEP+1
      DEP2=D(I)
      VEL2=V(I)
      S=SQRT((V0+VEL)*(V0-VEL))+SQRT((V0+VEL2)*(V0-VEL2))
      EXT=(DEP2-SDEP)*(VEL+VEL2)/S
      S=SQRT((V0+VCRI)*(V0-VCRI))
      EXT=EXT+(DCRIT-DCRI)*(VCRIT+VCRI)/S
      GO TO 40
   30 EXT=(DCRIT-SDEP)*(VCRIT+VEL)/SQRT((V0+VEL)*(V0-VEL))
   40 IF(DEP2-DCRI)50,70
   50 I1= IDEP+2
      DO 60 I=I1,ICRIT
   60 EXT=EXT+(D(I)-D(I-1))*(V(I)+V(I-1))/T(I)
   70 EXT=EXT*2.
C
C          CALCULATE RANGE
C
      S=SQRT((V0+VEL1)*(V0-VEL1))+SQRT((V0+VEL)*(V0-VEL))
      RANGE=(SDEP-DEP1)*(VEL+VEL1)/S
      DO 80 I=2,IDEP
   80 RANGE=RANGE+(D(I)-D(I-1))*(V(I)+V(I-1))/T(I)
      RETURN
      END
C
C
```

```
      SUBROUTINE TWO(V0,VCRIT,DCRIT,SDEP,D0,DTURN,
     1    VTURN,RANGE,EXT,THICK)
C
C         THIS SUBROUTINE CALCULATES THE RANGE, EXTENSION AND
C     THICKNESS OF THE SHADOW ZONE FOR THE 2 LAYER MODEL.
C
      IF(DTURN-SDEP) 10,20
   10 VEL=VTURN+(VCRIT-VTURN)*(SDEP-DTURN)/(DCRIT-DTURN)
      S=SQRT((V0+VEL)*(V0-VEL))
      EXT=2.*(DCRIT-SDEP)*(VCRIT+VEL)/S
      S=S+SQRT((V0+VTURN)*(V0-VTURN))
      RANGE=(SDEP-DTURN)*(VTURN+VEL)/S
      RANGE=RANGE+DTURN*(V0+VTURN)/SQRT((V0+VTURN)*(V0-VTURN))
      THICK=D0+(DTURN-D0)*(V0-VEL)/(V0-VTURN)
      GO TO 30
   20 VEL=VTURN+(V0-VTURN)*(SDEP-DTURN)/(D0-DTURN)
      S=SQRT((V0+VTURN)*(V0-VTURN))
      RANGE=SDEP*(V0+VEL)/S
      EXT=2.*(DCRIT-DTURN)*(VCRIT+VTURN)/S
      S=S+SQRT((V0+VEL)*(V0-VEL))
      EXT=EXT-2.*(SDEP-DTURN)*(VEL+VTURN)/S
      THICK=DTURN+(DCRIT-DTURN)*(VEL-VTURN)/(V0-VTURN)
   30 RETURN
      END
C
C
```



```
      SUBROUTINE BTRAN(V,D,N,S,PHI)
      DIMENSION V(1),D(1)
C
C         THIS SUBROUTINE CALCULATES THE SOUND VELOCITIES V(I)
C     AT DEPTHS D(I) FROM THE TEMPERATURE VALUES INITIALLY
C     STORED IN ARRAY V. S IS THE SALINITY AND PHI THE
C     LONGDITUDE
C
      DO 10 I =1,N
      V(I)=1493.+3.*(V(I)-10.)-0.006*(V(I)-10.)*(V(I)-10.)
     1    -0.04*(V(I)-18.)*(V(I)-18.)+1.2*(S-35.)-0.01*
     2    (V(I)-18.)*(S-35.)+D(I)/61.+1.E-7*D(I)*D(I)
     3    +2.E-10*D(I)*D(I)*(V(I)-18.)*(V(I)-18.)+1.E-4*
     4    D(I)*PHI/90.+2.0E-4*V(I)*(V(I)-5.)*(V(I)-25.)
   10 CONTINUE
      RETURN
      END
C
C
```

```
      SUBROUTINE FINTP(V,N,ITURN)
      DIMENSION V(1)
C
C         THIS SUBROUTINE FINDS THE MINIMUM ELEMENT OF
C     ARRAY V AND PLACES ITS SUFFIX IN LOCATION ITURN
C
      VMIN=V(1)
      DO 20 I=2,N
      IF(V(I)-VMIN)10,20
   10 VMIN=V(I)
      IMIN=I
   20 CONTINUE
      ITURN=IMIN
      RETURN
      END
C
C
```



```
      SUBROUTINE FIVAL(A,B,VALUE,RESLT,ISSCR,N1,N2)
      DIMENSION A(1),B(1)
C
C         THIS SUBROUTINE FINDS THE VALUE IN ARRAY B WHICH
C     CORRESPONDES TO "VALUE" IN ARRAY A AND PLACES IT IN
C     RESLT. N1 AND N2 ARE THE LIMITS OF THE ARRAY SUBSCRIPTS
C     SO ARRANGED THAT N2 IS THE SUBSCRIPT OF THE LARGEST
C     VALUE OF A.
C
      N=IABS(N1-N2)
      IF(N1-N2)10,20
   10 INCR=1
      GO TO 30
   20 INCR=-1
   30 DO 50 I1=1,N
      I=N1+INCR*I1
      J=I-INCR
      IF(VALUE-A(I))50,40
   40 DEL=(VALUE-A(I))/(A(J)-A(I))
      RESLT=B(I)+DEL*(B(J)-B(I))
      ISSCR=I
      GO TO 60
   50 CONTINUE
   60 RETURN
      END
```

```
FTN,L
C
C          J.P. 27-10-71
C
C          THIS IS THE SECOND SET OF SUBROUTINES FOR THE
C      PROGRAM SHAZO
C
      SUBROUTINE GRAT(INAME,ISCSU,DCRIT,LAYER,ISHAP)
      DIMENSION INAME(1)
C
C          THIS SUBROUTINE PRODUCES THE BASIC GRATICULE FOR
C      GRAPHIC DISPLAYS.
C
      CALL ERASE
      CALL HOME
      WRITE(16,10)
   10 FORMAT(/)
      CALL DOUBL
      IF(ISHAP)40,20
   20 WRITE(16,30)
   30 FORMAT(24X,"+")
   40 WRITE(16,50)(INAME(I),I=1,6)
   50 FORMAT(12X,"X & T  ",6(X,A1),"+")
      IF(LAYER)60,80,100
   60 WRITE(16,70)
   70 FORMAT(22X,"T W O    L A Y E R")
      GO TO 120
   80 WRITE(16,90)
   90 FORMAT(X)
      GO TO 120
  100 WRITE(16,110)
  110 FORMAT(22X,"M U L T I L A Y E R")
  120 CALL ALPHA
      WRITE(16,130)DCRIT
  130 FORMAT(/,27X,"CRITICAL DEPTH =",F8.2," METRES")
      IF(ISHAP)140,160
  140 WRITE(16,150)
  150 FORMAT(6X,"SOURCE +")
      GO TO 180
  160 WRITE(16,170)
  170 FORMAT(13X,"+")
  180 WRITE(16,190)ISCSU
  190 FORMAT("DEPTH SCALE = ",I5," M/UNIT")
      CALL DARK(23,631)
      CALL BRIGH(23,31)
      CALL BRIGH(1023,31)
      CALL BRIGH(1023,631)
      CALL BRIGH(23,631)
      DO 210 I=223,823,200
      CALL DARK(I,31)
      CALL BRIGH(I,63)
      DO 200 J=63,583,16
  200 CALL POINT(I,J)
      CALL DARK(I,599)
  210 CALL BRIGH(I,631)
      DO 230 I=151,511,120
```

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```
      CALL DARK(23,I)
      CALL BRIGH(55,I)
      DO 220 J=87,991,16
  220 CALL POINT(J,I)
      CALL DARK(991,I)
  230 CALL BRIGH(1023,I)
      CALL DARK(7,631)
      CALL ALPHA
      WRITE(16,240)
  240 FORMAT("0",//)
      IF(ISHAP)250,270
  250 WRITE(16,260)
  260 FORMAT("S"/"O"/"U"/"R"/"C"/"E"/)
  270 WRITE(16,280)
  280 FORMAT("D"/"E"/"P"/"T"/"H")
      RETURN
      END
C
C
```

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```
      FUNCTION ISCAL(RAMAX)
      DIMENSION ISC(3),XMAX(3)
C
C           THIS FUNCTION TAKES THE NEXT VALUE ABOVE RAMAX FROM
C     THE SERIES 1*10**N, 2*10**N, 5*10**N WHERE N=1,2,3.....
C
      ISC(1)=1
      ISC(2)=2
      ISC(3)=5
      XMAX(1)=5.
      XMAX(2)=10.
      XMAX(3)=25.
   10 DO 30 I=1,3
      IF(XMAX(I)-RAMAX)30,20
   20 ISCAL=ISC(I)
      GO TO 50
   30 CONTINUE
      DO 40 I=1,3
      ISC(I)=10*ISC(I)
   40 XMAX(I)=10.*XMAX(I)
      GO TO 10
   50 RETURN
      END
C
C
```

```
      SUBROUTINE DRTHS(Z,SDEP,VSDEP,ISDPT,DMAX,I0,ITURN,N,
     1    C,D,V,DIST1,DIST2,RAD)
      DIMENSION C(1),D(1),V(1)
C
C          THIS SUBROUTINE CALCULATES THE DISTANCES TO THE
C     VERTICES OF RAYS WHICH VORTEX AT A DEPTH Z AND ALSO
C     THE RADIUS OF THE RAYS AT THESE POINTS
C
      RSQ(A,B)=SQRT((A+B)*(A-B))
C
C          FIND VELOCITY AT DEPTH Z ETC.
C
      DSDPT=D(ISDPT)
      VSDPT=V(ISDPT)
      CALL FIVAL(D,V,Z,SK,IZPT,ITURN,I0)
      IZPT=IZPT+1
      DZPT=D(IZPT)
      VZPT=V(IZPT)
C
C          SK=SNELLS CONSTANT FOR THE RAY
C
      CALL FINEL(Z,D,SK,DLZ,ILZPT,N,ITURN)
      DLZPT=D(ILZPT)
      VLZPT=V(ILZPT)
C
C          FIND THE DISTANCE TO THE FIRST TURNING POINT
C
      DIST1=0.
      IF(1.E-4-VSDEP+VSDPT)3,7
    3 DIST1=(SDEP-DSDPT)*(VSDEP+VSDPT)/(RSQ(SK,VSDPT)+RSQ(SK,VSDEP))
    7 IF(ISDPT-IZPT)10,30,10
   10 J=IZPT-1
      DO 20 I=J,ISDPT
      IF(SK-V(I-1))17,13
   13 IF(SK-V(I))17,20
   17 DIST1= .
      DIST2=1.E10
      GO TO 140
   20 DIST1=DIST1+C(I)/(RSQ(SK,V(I-1))+RSQ(SK,V(I)))
   30 IF(1.E-4-SK+VZPT)40,45
   40 DIST1=DIST1+(DZPT-Z)*(VZPT+SK)/RSQ(SK,VZPT)
C
C          FIND THE DISTANCE TO THE SECOND TURNING POINT
C
   45 IF(Z-DMAX)60,50
   50 DIST2=DIST1
      GO TO 140
   60 IF(DLZ-D(ISDPT+1))70,90
   70 IF(1.E-4-SK+VSDEP)80,140
   80 DIST2=DIST1+2.*(DLZ-SDEP)*(SK+VSDEP)/(RSQ(SK,VSDEP))
      GO TO 140
   90 DIST2=DIST1+2.*(D(ISDPT+1)-SDEP)*(V(ISDPT+1)+VSDEP)/
     1    (RSQ(SK,V(ISDPT+1))+RSQ(SK,VSDEP))
      IF(ILZPT-ISDPT-1)100,120,100
  100 J=ISDPT+2
      DO 110 I=J,ILZPT
```

```
  110 DIST2=DIST2+2.*C(I)/(RSQ(SK,V(I-1))+RSQ(SK,V(I)))
  120 IF(1.E-4-SK+VLZPT)130,140
  130 DIST2=DIST2+2.*(DLZ-DLZPT)*(SK+VLZPT)/RSQ(SK,VLZPT)
C
C           CALCULATE RADIUS AT TURNING POINTS
C
  140 RAD=SK*(DLZPT-D(IZPT-1))/(V(IZPT-1)-VZPT)
      RETURN
      END
```